



Multivariate Analysis of Fish Diversity in Lokpalsagar Pond of Panna District in the Context of Habitat Related Variables

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Abstract:

Freshwater fish production constitutes a vital component of the global food system. Aquaculture is expanding rapidly to meet the protein requirements of a growing population, contributing approximately 68 million tons globally. Aquaculture accounts for the largest share of this production, particularly in Asia. Major groups of farmed fish, such as tilapia, carp, catfish, and pangasius, play a pivotal role in ensuring food security and supporting livelihoods in developing nations. Pond ecosystems, despite their relatively small size, are ecologically significant and support rich biodiversity. This study investigates the fish diversity of Lokpalsagar Pond, located in the Panna district of the Indian state of Madhya Pradesh. The investigation was conducted over a two-year period from November 2022 to October 2024 based on seasonal sampling carried out at four distinct sites, S1, S2, S3, and S4; this sampling encompassed the winter, summer, and monsoon seasons. The results revealed distinct seasonal variations in both fish diversity and abundance. The populations of major carp species such as *C. catla*, *C. carpio*, *C. mrigala*, and *L. rohita* remained stable, with an observed increase in their numbers during the monsoon season, indicating favorable environmental and breeding conditions. Species such as *L. calbasu* and *H. molitrix* remained consistently present across all seasons, demonstrating their high adaptability. Meanwhile, distinct seasonal fluctuations were observed in species such as *C. reba*, *C. marulius*, and *L. bata*, with their presence being more pronounced during the monsoon season. Catfish species like *M. singhala*, *M. cavasius*, and *C. batrachus* remained relatively stable, exhibiting only moderate seasonal variations. In contrast, species such as *H. fossilis* and *M. armatus* demonstrated a strong preference for the monsoon season, indicative of seasonal breeding or migratory patterns. The exotic species *O. mossambicus* remained consistently present throughout the year, reflecting its broad ecological tolerance.

Keywords: Fish, Diversity, Pond, Seasonal, Ecological

1. Introduction

Freshwater fish production remains an essential component of the global food system, and freshwater aquaculture is expanding rapidly to meet the demands of a growing population [1,2]. Examining the global landscape of freshwater fish production, the total output stands at approximately 68 million tons, of which 11 million tons are derived from capture fisheries and 57 million tons from aquaculture. Within this total production, aquaculture is increasingly becoming the dominant sector, particularly in Asia. Species include tilapia, carp, catfish, and pangasius species that are economically vital for food security and livelihoods in developing nations. Concurrently, there are numerous environmental challenges to address, such as issues related to water quality, habitat loss, and the impacts of climate change. Tilapia species rank among the most widely farmed freshwater species globally, particularly across Asia and Latin America. Carp species, specifically cyprinids, are at the forefront of the freshwater aquaculture sector in countries such as China, India, and Eastern Europe. Catfish

species, notably channel catfish and pangasius catfish, are also of significant importance, particularly in the USA and Vietnam. Freshwater shrimp species are also gaining rapid popularity, especially in Thailand and Vietnam. Freshwater aquaculture is experiencing rapid growth, particularly in Asia, where nations such as China, India, and Vietnam lead the world in terms of production volume. Freshwater fish account for approximately 35-40% of total global fish production. China alone produces roughly 60% of the world's freshwater fish supply. Freshwater fish, particularly those obtained from aquaculture farms, constitute a significant and affordable source of protein in many developing countries. The growing demand for affordable protein and efficient aquaculture methods has spurred the expansion of freshwater fish farming. Freshwater fishing serves as a source of livelihood for millions of people, particularly in rural and coastal regions. Fish farming provides employment opportunities to both small-scale farmers and large-scale commercial operators [3-6].

Freshwater ponds are vital aquatic ecosystems that globally support a wide range of biodiversity, including ichthyofauna. The structure, distribution, and abundance of ichthyofaunal communities are significantly influenced by environmental factors; among these, hydro-edaphic factors, specifically the physical and chemical properties of water and soil, play a crucial role [7,8]. Hydro-edaphic factors refer to the combined effects exerted upon an aquatic ecosystem by hydrological parameters such as water temperature, dissolved oxygen, pH, conductivity, turbidity, and nutrient concentrations, and soil properties such as sediment texture, organic matter content, and nutrient availability. These parameters directly and indirectly influence habitat quality, food availability, breeding grounds, and ecological equilibrium within the pond ecosystem [9].

Importance of Ponds

Ponds, small sources of freshwater, play a pivotal role in ecological balance, water management, and biodiversity. They serve multiple functions in both natural and human-modified landscapes, such as supporting aquatic life, providing water resources, and contributing to agriculture and fisheries [10, 11]. They hold immense significance globally, and particularly in India. Ponds constitute vital ecosystems that sustain a diverse array of species, including plants, insects, amphibians, fish, and birds. Ponds function as natural reservoirs where water accumulates, especially in regions characterized by seasonal rainfall [12]. They serve as a crucial buffer against drought and assist in regulating floodwaters during periods of heavy precipitation. In many rural areas, ponds serve as an essential source of water for crop irrigation. They are frequently utilized to store rainwater for use during dry spells, thereby enhancing their importance in water-scarce regions. Many ponds, particularly those situated in scenic and picturesque locations, are utilized for recreational activities such as fishing, boating, and birdwatching; in doing so, they also contribute to the local economy through eco-tourism [13]. Cultural Significance: In numerous regions, ponds also possess cultural and spiritual significance, and are often deeply intertwined with local customs and festivals.

Fish Diversity in Pond

Fish diversity in ponds plays a crucial role in maintaining the health, stability, and functioning of the ecosystem. Ponds, being small aquatic systems, rely on a diverse array of organisms to regulate processes such as nutrient cycling, food-web dynamics, and habitat structure. Fish constitute an integral part of these processes, and their diversity generates complexities that foster ecological balance [14-16].

Despite their small size, ponds serve as ecologically significant aquatic systems, playing a central role in sustaining local biodiversity and supporting a wide variety of ecological processes. Notwithstanding their relatively small dimensions, ponds contribute significantly to regional species richness and ecosystem services. These systems depend on a diverse range of organisms to regulate essential ecological functions; these include fish, aquatic invertebrates, plankton, macrophytes, and microorganisms [12, 17-19].

Water Quality

The physicochemical analysis of pond water typically involves the examination of five distinct physical parameters temperature, turbidity, total dissolved solids, and electrical conductivity and several chemical

parameters (pH, DO, BOD, COD, TH, TA, Cl₂, NO₃, PO₄, SO₄, Fe, F) to assess its quality and its suitability for various uses such as irrigation, drinking, and supporting aquatic life [20-24].

Analysis of Fish Diversity

The data collection, fish diversity is measured using biodiversity indices, such as species richness (S) (the total number of distinct species observed), the Shannon-Wiener index (H) (which reflects both species richness and evenness), the Simpson diversity index (D) (which measures the probability that two organisms randomly selected from a sample belong to the same species), and the evenness index (E) (which indicates how evenly organisms are distributed among different species) [25].

2. Material and methods

Study Area

This study was conducted at four sites Mongha (S1), Aghor (S2), Canal Point (S3), and Filter Point (S4), located at the Lokpalsagar pond in the Panna district of the Indian state of Madhya Pradesh. The study spanned two years, from November 2022 to October 2024, encompassing various seasons such as winter, summer, and monsoon. The geographical coordinates of the Lokpalsagar pond, situated in the Panna district, are 80°13'129" East Longitude and 24°43'213" North Latitude. It is situated in a climatic zone locally referred to as a "three-season region," which is considered ideal for agriculture. The climate of this district is generally warm; during the summer, the average maximum temperature reaches 40°C, while in the winter, the average minimum temperature drops to 15°C. The highest rainfall occurs during the three months from July to September, whereas the lowest rainfall is recorded in April and May, signaling the onset of the monsoon season.

Ichthyofaunal Analysis of Pond Water

The analysis of fish species—conducted using various methodologies—involved the study, identification, and assessment of fish species inhabiting a specific aquatic environment. This process was crucial for understanding the ecological health, biodiversity, and stability of freshwater ecosystems, such as ponds. In the assessment of fish species within pond waters, the scope of the ecosystems under consideration was kept relatively limited. Generally, this encompassed the following aspects: identification and classification of fish species; estimation of fish population sizes; analysis of species diversity and abundance; and investigation into the impact of ponds on fish communities [26-29].

Sampling Methods

Several techniques, such as trawling, were employed to collect fish samples from the pond. Methods such as gill nets, seine nets, and trawl nets were utilized to collect fish for analysis [30].

Species Identification

The collected fish specimens were identified down to the species level using a taxonomic field guide. During this identification process, the morphology of the fins of each specimen was also determined to aid in accurate classification [31-33].

Estimation of Abundance and Biomass

To understand the dynamics of fish populations, their biomass was estimated. This metric assessed the relative abundance of a species based on the number of fish caught per hour of fishing effort [34-36]. A common method for estimating population size was the 'mark-recapture' technique. In this method, a small group of fish was marked, released, and subsequently recaptured. The ratio of marked to unmarked fish in the second sample was used to estimate the total population size.

Mark-Recapture Formula:

$$N = M \times \frac{C}{R} \dots \dots \dots 22$$

Where:

N = estimated total population size

M = number of fish marked and released

C = total number of fish caught in the second sample

R = number of marked fish recaptured in the second sample

Results and discussion

Experimental data derived from samples collected from the Lokpalsagar pond, located in the Panna district of Madhya Pradesh, were analyzed. The results were interpreted based on water quality parameters, soil characteristics, and fish species diversity; these findings were obtained from four designated study sites known as Monga (S1), Aghor (S2), Canal Point (S3), and Filter Point (S4), across three seasons (winter, summer, and monsoon) over two years (2022-23 and 2023-24).

Ichthyofaunal Analysis in 2022-23

During the study period, which spanned from November 2022 to October 2023, eighteen fish species belonging to five orders and seven families were recorded in varying numbers across four distinct sites (S1, S2, S3, and S4) within the Lokpalsagar pond; this period encompassed three distinct seasons: winter, summer, and monsoon.

Species of the order Cypriniformes, specifically those belonging to the family Cyprinidae, were observed in large and consistent numbers across all seasons. *Catla catla*, *Cyprinus carpio*, *Cirrhinus mrigala*, *Labeo rohita*, and *Hypophthalmichthys molitrix* were consistently present in large numbers throughout the winter, summer, and monsoon seasons, demonstrating their robust adaptability to changing environmental conditions. The *Labeo calbasu* was also present in large numbers during the winter and monsoon, although a slight decline in its population was observed during the summer months. The *Labeo bata* was present in moderate numbers during the winter, but its population experienced a significant surge during the summer and monsoon seasons, a phenomenon that can likely be attributed to breeding activities or food availability. Conversely, *Labeo gonius* and *Cirrhinus reba* were rarely observed during the winter and monsoon, and were absent during the summer; this scarcity was likely due to their sensitivity to high temperatures or the prevailing habitat conditions during the dry months [37, 38]. Fish species belonging to the order Siluriformes exhibited distinct seasonal distribution patterns. Within the family Bagridae, both *Mystus singhala* and *Mystus cavasius* were present in large numbers during the winter and monsoon, whereas during the summer, they were found only in moderate numbers, a pattern likely reflecting a partial decline associated with fluctuations in temperature or water levels. The *Wallago attu* was observed only occasionally during the winter and monsoon seasons and was completely absent during the summer; this suggests that, during the warmer months, this species likely retreated to deeper waters [39, 40]. Within the family Clariidae, *Clarias batrachus* was present in moderate numbers during the winter and summer seasons, whereas its population increased significantly during the monsoon season. In contrast, the species *Heteropneustes fossilis*, belonging to the family Heteropneustidae, was completely absent during the winter and summer and was observed only during the monsoon; this indicates a strong seasonal dependence, linked either to reproduction or to habitat expansion facilitated by the monsoon [41, 42] (Table 1)

Table 1: Analysis of total fish species in Lokpalsagar Pond												
S. No.	Order	Family	Scientific name	Common name	2022-23				2023-24			
					Winter	Summer	Monsoon	Frequency	Winter	Summer	Monsoon	Frequency
1	Cypriniformes	Cyprinidae	<i>Catla catla</i>	Catla, Katla	++ +	+++	+++ +	10	++ +	+++	+++ +	10
2			<i>Cyprinus carpio</i>	Badhas	++ +	+++	+++ +	10	++ +	+++	+++	9
3			<i>Cirrhinus mrigala</i>	Mrigal	++ +	+++	+++ +	10	++ +	+++ +	+++	10
4			<i>Labeo calbasu</i>	Kariya, Kalaunt	++ +	+++	+++	9	++	+++	+++ +	9
5			<i>Labeo rohita</i>	Rohu	++ +	+++	+++ +	10	++ ++	+++	+++	10
6			<i>Labeo bata</i>	Bata, Rahia	+	+	++	4	+	-	+++	4
7			<i>Hypophthalmichthys molitrix</i>	Vikit	++ ++	+++	+++	10	++ +	+++	+++	9
8			<i>Labeo gonius</i>	Kursa	++	+++	+++	8	++ +	++	++	7
9			<i>Cirrhinus reba</i>	Naren	++	-	+	3	+	++	+	4
10	Siluriformes	Bagridae	<i>Mystus singhala</i>	Singhara	++ +	+++	+++	9	++ +	+	+++	7
11			<i>Mystus cavasius</i>	Kitua	++ +	++	+++ +	9	++	+++	+++	8
12			<i>Wallago attu</i>	Lonch, Padhin	+	-	++	3	++	+	+	4
13		Clariidae	<i>Claris batrachus</i>	Catfish, Mangur	++	+++	+++	8	++ +	++	++	7
14		Heteropneustidae	<i>Heteropneustes fossilis</i>	Singhi	-	-	++	2	++	-	++	4
15	Perciformes	Chandidae	<i>Channa marulius</i>	Sol, Sawal	++	-	+	3	++	-	+	3
16			<i>Oreochromis mossambicus</i>	Tilapia	++ +	+++	+++	9	++	+++	+++	8
17	Osteoglossiformes	Notopteridae	<i>Notopterus notopterus</i>	Suja, Patola	+	-	++	3	+	-	+	2
18	Synbranchiformes	Mastacembelidae	<i>Mastacembelus armatus</i>	Bam	-	-	++	2	+	+	++	4
Total	5	7	18	18	39	33	50	122	41	34	44	119

Distinct seasonal variations were observed within the Order Perciformes and the Family Chandidae. The *Channa marulius* was found in low numbers during the winter and monsoon seasons, and was absent during the summer; this suggests that the species avoids higher temperatures and migrates to new, more favorable habitats. Conversely, *Oreochromis mossambicus* was found in large numbers during the winter, in moderate numbers during the summer, and again in large numbers during the monsoon; this demonstrates its robust adaptability and perhaps a broad temperature tolerance range enabling it to thrive across all seasons [43]. The *Notopterus notopterus*, belonging to the Family Notopteridae within the Order Osteoglossiformes, was observed in low

numbers during the winter and monsoon seasons but was completely absent during the summer. Its limited presence suggests that this species may be sensitive to the warm conditions or water scarcity characteristic of the summer season [44, 45]. The *Mastacembelus armatus*, a member of the Family Mastacembelidae within the Order Synbranchiformes, was observed exclusively during the monsoon season and was completely absent during both winter and summer. Its presence solely during the rainy season highlights its strong ecological association with the changes brought about by the monsoon, such as rising water levels, dropping temperatures, and reproductive behaviors [46, 47] (Table 1).

Frequency analysis of fish

An analysis of the observed and estimated frequencies of various fish species during the winter, summer, and monsoon seasons of 2022-23 revealed consistent patterns, as well as species-specific fluctuations. India's major carp species, *Catla catla*, *Cyprinus carpio*, *Cirrhinus mrigala*, and *Labeo rohita*, succeeded in maintaining stable populations across all seasons. Their observed counts largely corresponded with the estimated values. For all four species, the observed count was 3 during both winter and summer, and 4 during the monsoon, which aligns with the predicted increase in numbers during the rainy season. This indicates a strong seasonal effect, wherein the monsoon contributes to greater availability and likely breeding activity for these species. The *Labeo calbasu* also exhibited consistent observations across all seasons, with an average count of 3 during winter, summer, and monsoon values that were very close to the estimated figures of 2.88, 2.43, and 3.69, respectively. The observed counts for *Labeo bata* were low 1 during winter and summer, and 2 during the monsoon, reflecting its limited presence; nevertheless, these figures still reflected the predicted seasonal upward trend indicated by the estimates. The observed presence of the exotic species *Hypophthalmichthys molitrix* was slightly higher in winter 4, observed versus 3.20 estimated, and largely corresponded with the estimates for the summer and monsoon seasons.

This demonstrates its adaptability to various seasons, although it was found in the highest abundance during the winter. The *Labeo gonius* exhibited a gradual increase from winter through the monsoon season. Observed counts were 2, 3, and 3, which align with the estimated trends of 2.56, 2.16, and 3.28. Some smaller local species, such as *Channa reba* and *Channa marulius*, displayed greater variability. The observed frequency of *C. reba* in winter was 2, which was considerably higher than the estimated 0.96, yet it was completely absent in summer, despite its estimated frequency for that season being 0.81. During the monsoon season, it reappeared with a frequency of 1, which was close to its estimated frequency. Similarly, *C. marulius* was recorded twice in winter, was absent in summer, and was observed once during the monsoon season; this pattern reflects a tendency toward seasonal fluctuations and occasional appearances. Catfish species such as *M. singhala*, *M. cavasius*, and *C. batrachus* were consistently recorded across all seasons. The frequency of *M. singhala* was 3 in all three seasons, which was very close to its estimated frequency. The count of *M. cavasius* declined in summer, it was observed twice, whereas the estimated frequency was 2.43, but rose to 4 during the monsoon season, which was slightly higher than its estimated frequency of 3.69. The frequency of *C. batrachus* sightings increased from winter through the monsoon season, 2, 3, and 3, indicating a trend consistent with its seasonal abundance. Species such as *W. attu*, *N. notopterus*, and *H. fossilis* were observed primarily during the monsoon season. The *W. attu* was observed once during the winter and twice during the monsoon, but not at all during the summer; this was consistent with the low numbers predicted for that season. The *H. fossilis* and *M. armatus* were not observed at all during the winter and summer, even though their predicted values were moderate, yet during the monsoon, both appeared with a frequency of 2, which was significantly higher than their predicted values of 0.82. This indicates a strong preference for the monsoon season or a high frequency of occurrence during that specific period. Finally, *O. mossambicus* remained consistently present across all seasons, with a frequency of 3. This frequency was very close to the predicted frequencies 2.88, 2.43, and 3.69, reflecting its year-round abundance and broad environmental tolerance (Figure 1).

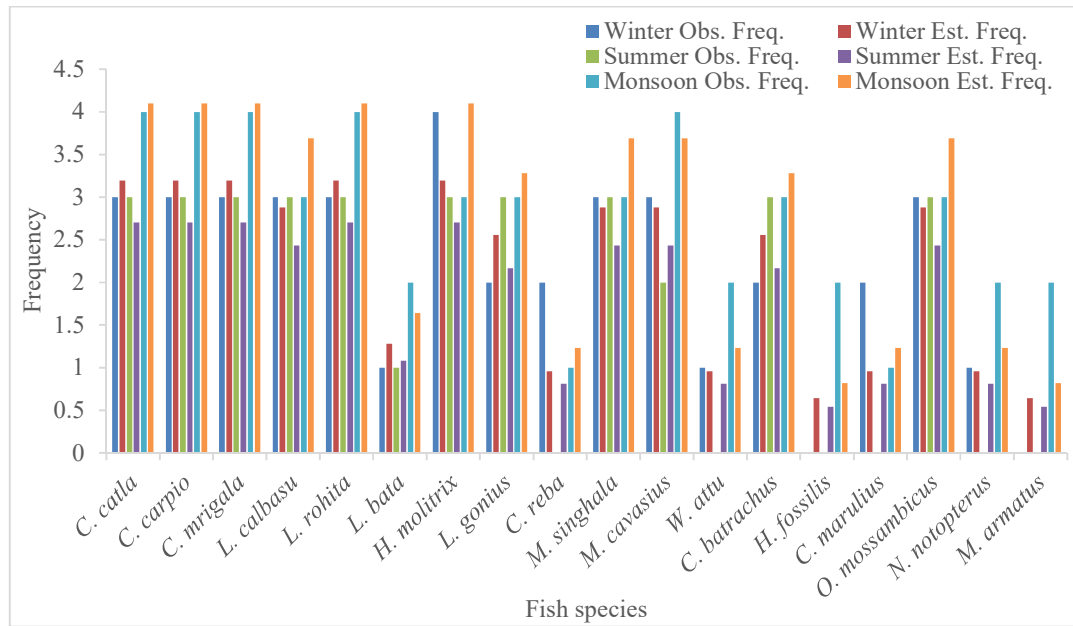


Figure 1: Fish species analysis (Obs. freq. vs. Est. freq.) in 2022-23.

Simpson diversity in 2022-23

Simpson Index (D): This measures low dominance, which indicates high diversity. It was interpreted as follows: highest diversity, lowest dominance during the monsoon season $D=0.062$, moderate diversity in winter $D=0.070$, and lowest diversity, highest dominance in summer $D=0.087$.

Simpson Diversity Index (1-D): This measures the probability that two randomly selected organisms will belong to different species. It was interpreted as follows: highest species diversity during the monsoon season, 0.938, slightly lower than the monsoon season in winter, 0.930, and lowest seasonal diversity in summer, 0.913.

Simpson Reciprocal Index (1/D): The number of dominant species; this value was slightly higher during the summer, 1.0885, indicating a slightly more even distribution of dominance among species, despite the overall lower diversity, whereas it remained approximately equal, ~ 1.068 , during the winter and monsoon seasons (Table 2).

Table 2: Simpson's Diversity of Fish in Lokpalsagar Pond						
Seasons	2022-23			2023-24		
	(D)	(1-D)	(1/D)	(D)	(1-D)	(1/D)
Winter	0.07	0.93	1.076	0.0637	0.9363	1.068
Summer	0.087	0.913	1.096	0.0813	0.9187	1.0885
Monsoon	0.062	0.938	1.067	0.064	0.936	1.0684

Quantitative Analysis of Fish in 2023-24

During a study conducted at Lokpalsagar Pond between November 2023 and October 2024, eighteen fish species belonging to five orders and seven families were recorded in varying numbers across four distinct sites, S1, S2, S3, and S4, and three different seasons winter, summer, and monsoon.

During the winter season, members of the family Cyprinidae, which belongs to the order Cypriniformes, were generally found in abundance within the local freshwater ecosystem. Species such as *Catla catla*, *Cirrhinus mrigala*, *Labeo rohita*, and *Hypophthalmichthys molitrix* were particularly abundant, and their populations

remained significantly high across all three seasons. The *Cyprinus carpio* was quite common in winter and was found in even greater numbers during the summer and monsoon months. Similarly, *Labeo calbasu* and *Labeo gonius* were slightly less common in summer, but their numbers increased during the winter and monsoon seasons. *Labeo bata* was moderately common in winter and summer, and its numbers increased with the onset of the monsoon season. However, the seasonal presence of *Cirrhinus reba* was limited; its numbers were low during winter and monsoon, whereas it was found in moderate numbers during the summer [37, 38]. Cyprinids proved to be the backbone of the fish diversity, particularly during the monsoon season, when their numbers reached their peak due to favorable conditions for breeding and foraging (Table 1).

Members of the order Siluriformes exhibited distinct seasonal patterns. Within the family Bagridae, *Mystus cavasius* was found in the highest numbers during the winter, although its abundance declined during the warmer months. The *Mystus singhala* was present in moderate numbers during the winter and monsoon seasons but was rarely observed during the summer. The *Wallago attu* was present in moderate numbers during the winter; however, its presence was very limited during the warmer months [39, 40]. A representative of the family Clariidae, *Clarias batrachus*, remained consistently present across all three seasons and was found in moderate numbers throughout the year. In contrast, *Heteropneustes fossilis*, a member of the family Heteropneustidae, was found in moderate numbers during the winter but was almost absent during the summer, reappearing only occasionally during the monsoon season. These catfish species generally prefer cold, oxygen-rich waters; however, some species were well-adapted to survive even in shallow-water conditions during the summer months [41, 42].

Species belonging to the family Channidae, order Perciformes, displayed significant variations in their seasonal abundance. The *Channa marulius*, an apex predator, was observed only occasionally during the winter and monsoon seasons and was completely absent during the summer. Conversely, *Oreochromis mossambicus* proved to be a more resilient species, remaining consistently present during both the winter and summer months, while being found in significantly higher numbers during the monsoon season. Tilapia's ability to adapt to changing water conditions, coupled with its rapid reproductive cycle, established it as a dominant species during the rainy season [43]. The family Notopteridae order Osteoglossiformes was represented by *Notopterus notopterus*, which was completely absent during both the winter and summer months but appeared in limited numbers during the monsoon season. Its presence was likely linked to the elevated water levels and the availability of aquatic vegetation during the rainy season, which provided an ideal habitat for breeding and foraging [44, 45]. The *Mastacembelus armatus*, belonging to the family Mastacembelidae and order Synbranchiformes, remained consistently present across all three seasons, albeit in low numbers. This species was relatively rare; nevertheless, its ability to survive in low-oxygen conditions and inhabit burrows beneath the surface enabled it to persist throughout the year, despite its scarcity [46, 47] (Table 1).

Frequency analysis of fish

An analysis of data on seasonal fish species for the 2023-24 period, comparing observed frequencies against estimated frequencies across the winter, summer, and monsoon seasons, revealed several significant patterns. Most species adhered closely to expected trends, while others exhibited distinct seasonal preferences and deviations, pointing to specific ecological and behavioral responses. The major carp species *Catla catla*, *Cyprinus carpio*, *Cirrhinus mrigala*, and *Labeo rohita* emerged as the most dominant in terms of presence and consistency. The *C. catla* maintained consistent observed frequencies of 3, 3, and 4 across all seasons, closely aligning with estimated values of 3.45, 2.86, and 3.70; this indicates its expected presence throughout the year, with a slight increase observed during the monsoon season. The *C. carpio* remained stable across all seasons, recording an observed frequency of 3, nearly identical to its estimated values, thereby confirming its broad adaptability. The presence of *C. mrigala* appeared slightly elevated during the summer, 4 observed vs. 2.86 estimated, possibly indicating its peak abundance or an increased likelihood of being caught during warmer conditions. The *L. rohita* was most prominent during the winter, with 4 observed vs. 3.45 estimated, and persisted through the other seasons as well, underscoring its year-round prevalence. The *L. calbasu* demonstrated increasing abundance, rising from an observed frequency of 2 in winter to 4 in the monsoon season; this trend aligns with estimates predicting its

increased abundance and suggests either a preference for the monsoon season or a greater likelihood of detection during that period. In contrast, the presence of *L. bata* was minimal 1 during winter and completely absent 0 during summer; however, during the monsoon, it surged to 3, a figure significantly higher than its estimated value of 1.48. This pattern indicates a strong seasonal preference for wet conditions, likely linked to reproductive behavior or habitat suitability during the monsoon season. Among exotic species, *H. molitrix* exhibited remarkable consistency across all seasons, recording an observation frequency of 3 in every season, a figure quite close to its estimated values of 3.10, 2.57, and 3.33. This reflects its high adaptability to changing environmental conditions. The *L. gonius* and *C. reba* displayed mixed seasonal trends. The presence of *L. gonius* was higher in winter 3, against an estimate of 2.41, followed by a subsequent decline. The *C. reba* was found in lower numbers during the winter and monsoon seasons 1, yet it showed a higher-than-expected increase during the summer 2, against an estimate of 1.14, signaling potential shifts in its seasonal behavior or habitat utilization. Seasonal variations were more pronounced among catfish species, such as *M. singhala* and *M. cavasius*. The presence of *M. singhala* remained stable during the winter and monsoon seasons 3; however, despite high estimated values, its numbers declined significantly during the summer 1. The *M. cavasius* demonstrated an increasing trend from winter through the monsoon season 2 and 3, which was consistent with its projected growth and indicative of its distinct seasonal behavior. The *C. batrachus* exhibited a declining trend from winter 3 through the monsoon season 2, a figure slightly lower than predicted, suggesting that either their population numbers were low or they were captured less frequently during the latter months of the year. The presence of *W. attu* and *C. marulius* remained low but stable; *W. attu* was present in all seasons, whereas *C. marulius* was not observed during the summer. This observation aligns with ecological expectations that these species are more active or more easily detected during the colder and wetter months. Species such as *H. fossilis* and *M. armatus* clearly demonstrated seasonal preferences. The *H. fossilis* was not observed during the summer but was recorded during the winter and monsoon seasons; in these months, the observed figures exceeded the predicted abundance 2. A similar pattern was observed in *M. armatus*; it was most frequently observed during the monsoon season 2, against a prediction of 1.48, suggesting that this species is more active in activities such as breeding or migration during this period. The *O. mossambicus* exhibited stability; its observed numbers showed a consistent upward trend 2, 3, and 3, which closely matched the predicted figures. This suggests that this non-native species successfully adapts to the local environment, thereby maintaining a stable presence throughout the year. The *N. notopterus* appeared very rarely; it was observed only once each during both the winter and monsoon seasons. This observation is consistent with its low predicted abundance and indicates that this species is either scarce or not easily detected (Figure 2).

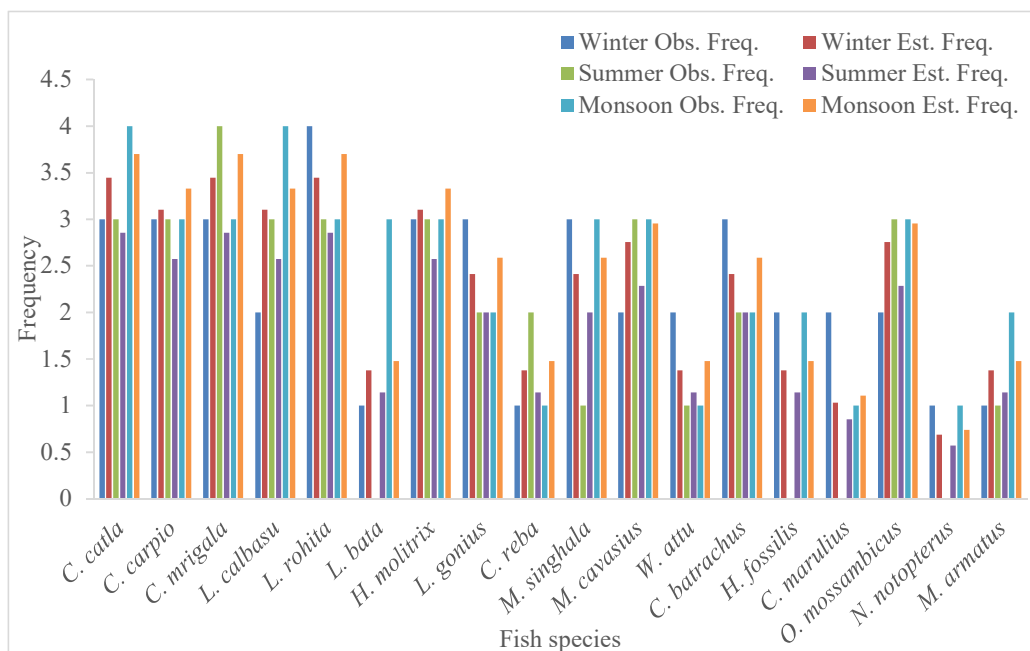


Figure 2: Fish species analysis (Obs. freq. vs. Est. freq.) in 2023-24.

Simpson diversity in 2023-24

Simpson Index (D): Lower values indicate higher diversity. Specifically, diversity was lowest during the summer $D=0.0813$, accompanied by high dominance; conversely, during the winter $D=0.0637$ and monsoon $D=0.0640$ seasons, diversity was very similar and exceptionally high.

Simpson Diversity Index (1-D): The probability that two randomly selected organisms belong to different species; this value was highest and nearly equal during the winter 0.9363 and monsoon 0.9359 seasons, while it was slightly lower during the summer 0.9187.

Simpson Reciprocal Index (1/D): The number of dominant species; this value was slightly higher during the summer, 1.0885, indicating a slightly more even distribution of dominance among species, despite the overall lower diversity, whereas it remained approximately equal, ~ 1.068 , during the winter and monsoon seasons (Table 2).

3. Quantitative Analysis of Fish Classification

During the years 2022-23 and 2023-24, a quantitative analysis of fish classification was conducted at both the Order and Family levels. The data revealed that across different sampling seasons, distinct trends were observed regarding the distribution and dominance of various taxonomic groups. At the Order level, the most dominant group was Siluriformes, accounting for 43% of the total fish species observed. This Order comprises several significant catfish species, known for their adaptability and their presence across diverse freshwater environments. Their high abundance reflects their robust ecological presence across different seasons, suggesting that environmental conditions during both years were favorable for species belonging to this order that are often benthic bottom-dwelling and nocturnal.

Cypriniformes, which constituted 14% of the total Orders, was less dominant; however, it included several economically significant food and aquaculture species, such as *Catla catla*, *Labeo rohita*, and *Cirrhinus mrigala*. Despite their lower taxonomic frequency at the Order level, the high abundance of individual species and their consistent presence across different seasons underscored their economic and ecological importance. Orders such as Perciformes, Osteoglossiformes, and Synbranchiformes collectively contributed 14% to the total Order representation. These groups, although fewer in number, nonetheless included unique and regionally specific species such as *Oreochromis mossambicus*, *Notopterus notopterus*, and *Mastacembelus armatus*. Their presence indicated a wide range of biodiversity and habitat diversity within the studied water bodies, reflecting a healthy aquatic ecosystem. At the family level, Cyprinidae was clearly dominant, accounting for 50% of all fish species observed during both years. This dominance was consistent with the prevalence of carp species in the seasonal data and confirms the central role of this taxon in inland fisheries. Their broad adaptability, tolerance to environmental variations, and significance in Indian aquaculture contributed to their numerical and ecological dominance.

Within the order Siluriformes, three families were recorded: Bagridae (17%), Clariidae (6%), and Heteropneustidae (6%). *Mystus* species of the Bagridae family were common and frequently observed across all seasons, while *Clarias batrachus* and *Heteropneustes fossilis* represented their respective families. These species generally exhibited a strong seasonal preference, thriving particularly during the monsoon season; consequently, their overall numbers remained at moderate levels. Within the Perciformes group, the Chandidae family constituted 11% of the population. Given the limited number of species in this group, this proportion is notably high. This reflects the regular presence of *O. mossambicus*, a robust and widely distributed exotic species, and its significant contribution to the total population. The Notopteridae population stood at 6%, while the share of Mastacembelidae was also 6%. These groups comprised rare or seasonally active species, and habitat requirements were often highly specialized. Their low numbers suggest that their distribution within the sampled areas was quite limited, or that they appeared only sporadically (Figure 3).

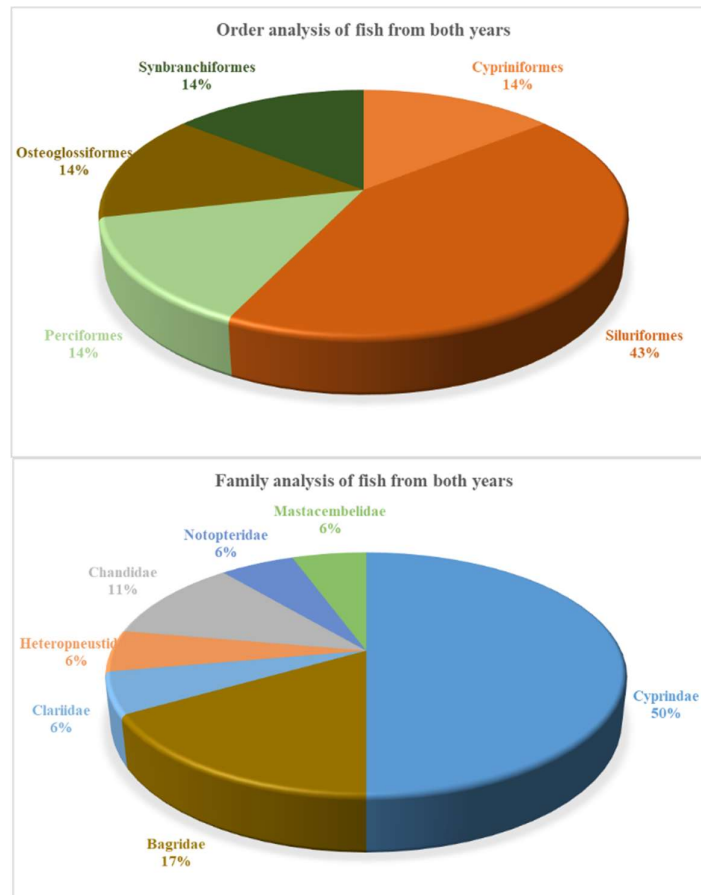


Figure 3: Analysis of fish taxonomic order and family for both years

Fish growth analysis across seasons

In 2022-23, the total fish growth was distributed as follows as 29.17% in winter, ~30.23% in summer, and ~40.60% during the monsoon season. The monsoon season proved to be the most productive, contributing the largest share to the total fish growth. The summer season ranked second, while the winter season observed the lowest growth. During 2022-23, the monsoon season played a significant role in fish growth, thereby highlighting its importance for aquaculture productivity during that year.

The percentage contribution of the monsoon season stood at approximately 36.31%, constituting the largest share; this was followed by the winter season at approximately 32.06% and the summer season at approximately 32.52%, ranking second and third, respectively. The monsoon season made the highest contribution to the total fish growth. The contributions of the winter and summer seasons were nearly equal, and together they accounted for approximately one-third of the total growth. In 2023-24, the monsoon season remained the most productive; nevertheless, the winter and summer seasons also played significant roles, reflecting a more balanced seasonal distribution of fish growth compared to the previous year (Figure 4).

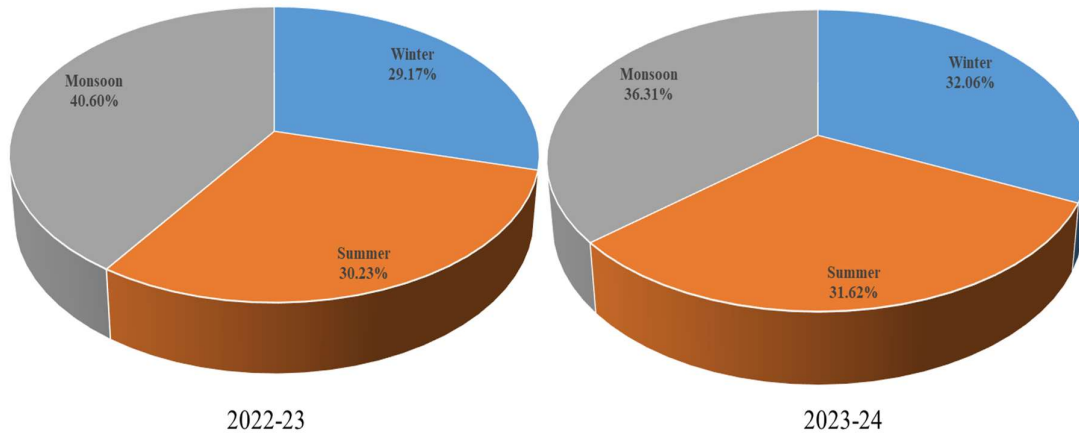


Figure 4: Seasonal variations in both years with fish growth.

Year-over-Year Fish Growth Analysis

The percentage change in fish growth increased to +5.96% during the winter and +0.83% during the summer, after which it declined to -13.80% during the monsoon season. A significant increase in fish growth was observed during the winter, indicating that productivity was higher during this season. A slightly positive change was noted in the summer, suggesting that growth remained largely stable. A substantial decline was observed during the monsoon season, wherein fish growth decreased by approximately 14%, thereby reversing the previous dominant trend (Figure 5). Between 2022-23 and 2023-24, the growth pattern shifted; productivity during the summer exceeded that of the winter, while a significant decline in production was observed during the monsoon season. This suggests that potential changes in environmental and agricultural conditions have impacted the seasonal growth of fish.



Figure 5: Segregation analysis of fish in different seasons

4. Conclusion

This study demonstrates the presence of a diverse and ecologically balanced fish community in Lokpalsagar Pond, where seasonal variations exert a distinct influence on both species composition and abundance; thus, the study underscores the importance of sustainable development. The findings of this study point to a diverse and seasonally influenced fish community, serving as an indicator of a stable and healthy freshwater ecosystem.

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